Case Study: Low-cost, high quality alternative steam generation for silicon dioxide in thick film applications

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SUMMARY

Many product sectors of the high-tech infrastructure equipment industry are under price pressure. Several forces account for this pressure, but the bottom line is that these sectors must relentlessly pursue cost-reduction opportunities in order to maintain profitability and/or acceptable gross margins.

This case study covers a successful cost reduction project at one high-tech equipment manufacturer's wafer fab operation (WFO). The WFO qualified a new steam generation and purification system for use in thermally growing a thin silicon dioxide (TOx) layer on silicon. This 10-15 micron TOx layer forms the base under-cladding for the company's advanced nano device chip fabrication. The steam generation system, manufactured by RASIRC, offers significant cost savings through elimination of hydrogen and oxygen gas. The test results for critical success data met or exceeded the WFO's current TOx growth process. The WFO is now retrofitting additional TOx chambers on its diffusion furnaces with the new RASIRC® Steamer.

The WFO expects the cost of ownership to dramatically decrease after the complete retrofit. Estimated benefits from retrofitting with RASIRC Steamers include:

1. Cost Reduction: 5%, *without* sacrificing product performance, yield, or reliability.
2. TOx Capacity Increase: 17% per TOx furnace tube.
3. Maintenance and repair cost: Negligible.
4. ROI: One fiscal quarter (after qualification).

After implementation, WFO concluded that the Steamer was ideal for thick or thin oxide growth applications where any of the following conditions exist:

- Film growth rate, thickness uniformity, low stress, and reliability/uptime are paramount.
- Existing or planned pyrolytic steam process costs are prohibitive.
- No gas infrastructure exists at the facility for steam generation.

THE CHALLENGE

Maintaining profitability and acceptable gross margin levels in many high-tech infrastructure equipment sectors is a challenge because of on-going pressures on average sales price (ASP). Many predict this trend to continue in the foreseeable future, and companies must reduce operating expenses. The TOx generation process was identified by the WFO as an area of excessive cost and potential savings.

Semiconductor-grade silicon is the starting material used to form the base under-cladding for the WFO's advanced nano device fabrication, with a 10-15 micron thick TOx film thermally grown using steam. Key parameters that cannot be compromised are: thickness targeting, thickness uniformity, low stress (low bow)/stress uniformity, and refractive Index (RI) uniformity (within wafer, within batch, and batch-to-batch).

The pyrolitic torch method has been the industry standard for TOx growth. This method combines high purity hydrogen and oxygen gas to form steam that then diffuses oxygen into the silicon wafer, forming the TOx layer. Significant increases in the cost of hydrogen over the past 3-4 years plus excessively high costs to install bulk hydrogen and oxygen systems have made the pyrolitic torch method cost prohibitive.

THE SOLUTION

With the increase in WFO production levels and the pressing need for cost-reduction, finding an alternate steam generation option became a high priority. WFO needed a low-cost, high purity steam-generating solution that would greatly reduce total fab operating cost, while still delivering consistently high yielding, high quality TOx films for their advanced nano device fabrication. WFO selected the RASIRC Steamer, which uses de-ionized water as its steam source, thus eliminating all dependence on hydrogen and oxygen gas. Designed for industrial applications, the RASIRC Steamer creates ultra high purity steam using controlled delivery systems and steam purifiers.

The RASIRC Steamer uses a non-porous hydrophilic membrane that selectively allows water molecules to pass. The membrane is 1,000,000 times more selective for water molecules compared to nitrogen molecules. In the vapor phase, the membrane only allows water. All other molecules are greatly restricted, so contaminants in water such as dissolved gases, ions, TOCs, particles, viruses, bacteria, pyrons, and metals can be removed in the steam phase.

Older water bubbler technologies required a carrier gas to deliver water vapor to the chamber. The RASIRC Steamer eliminates the need for a carrier gas by generating ultrapure steam at a constant positive pressure. Using a proprietary membrane developed by RASIRC, the steam is purified and the flow rate is controlled across the nonporous surface area. (1, 2) By eliminating

the carrier gas and blanketing the entire furnace tube in pure water vapor, even the loading end of the furnace tube reaches maximum theoretical growth rate.

The RASIRC Steamer combines a clean steam generator and steam purification assembly into a single system. All wetted components in the liquid path are quartz or Teflon®. The purified steam path components are quartz and Teflon® fittings and valves. Previous data from foundries growing thick oxide indicated that the RASIRC Steamer could increase oxide growth rate, chamber uniformity, and film quality, and/or reduce operating cost when compared against all other steam technologies. (3)

QUALIFICATION

Based on field data on thick oxide from RASIRC, the WFO recently qualified the RASIRC Steamer with positive results. Qualification included:

- Critical parameter comparison of RASIRC Steamer versus the Plan of Record (POR) pyrolitic torch method.

- Final TOx film thickness: greater than 10 microns

- Critical Parameters:
    - Thickness and Uniformity
    - Growth rate
    - Wafer bow
    - Refractive index (RI) and RI uniformity

- Success criteria: meet or exceed POR (baseline) data

- Setup:
    - Horizontal furnace tube – containing 150 wafers (minimum)
    - Sampling Plan:
        - Six prime grade silicon (SEMI Standard) samples measured: 2 in source zone, 2 in middle zone, and 2 in load zone.
    - Measurements - taken at 80 hour intervals, and end of run
        - 13 data points per wafer

RESULTS

All critical parameters met or exceeded current POR results. Repeat runs have demonstrated process stability.

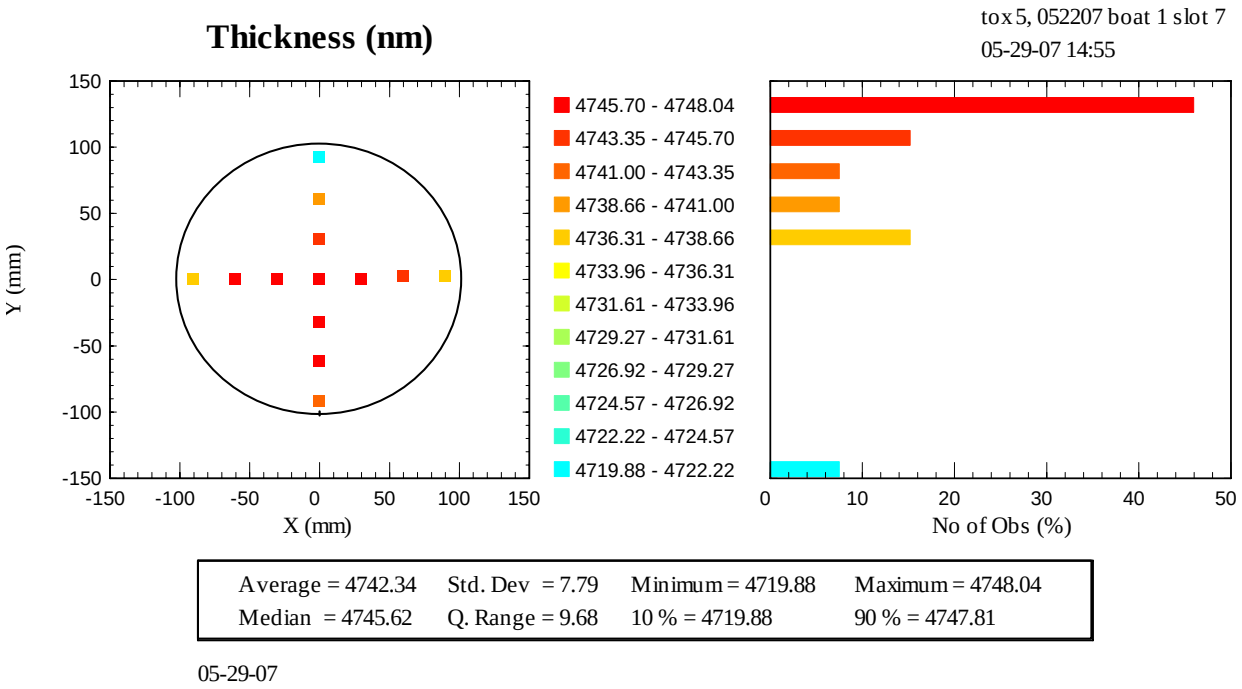
TABLE 1 – RESULTS AND COMPARISON – THICKNESS > 10 micron

Table 1A - Wafer Level Results

PARAMETER	POR (BASELINE)	RASIRC Steamer	COMPARISON
Refractive Index (RI) @ 632 nm	1.45818	1.45811	Equivalent
Refractive Index (RI) sigma	< 4.0E-5	<4.0E-5	Match
Thickness Uniformity	<0.5%	<0.5%	Match
Wafer Bow (micron)	<30	<30	Match
Growth Rate to desired thickness (hr)	~500	~500	Slightly Better
Weekly Operating Time (hrs)	121-132	168	Improvement

Table 1B - Device-Level Results

PARAMETER	POR (BASELINE)	RASIRC Steamer	COMPARISON
Propagation Loss (dB)	-1.41	-1.53	Equivalent
PDL (dB)	0.57	0.59	Equivalent



NEXT STEPS AND COST SAVINGS IMPACT

With the successful qualification of the RASIRC Steamer, the WFO is now in the process of retrofitting their other TOx furnace tubes. Based on current production levels and operating costs, the RASIRC Steamers will reduce the *total* fab operating cost by *nearly 5%,* primarily through the elimination of hydrogen and oxygen gas use. Additionally, with the ability to run an uninterrupted TOx growth process, total cycle times are reduced by approximately 17% based on total operating cycle (including maintenance periods), providing a significant throughput capacity increase.

COST OF OWNERSHIP COMPARISON

When looking at new installations, whether green field, facility expansion, or dry to wet oxidation conversion, it is important to review both material and infrastructure costs as well as permitting requirements.

There are three basic approaches when adding new wet thermal oxidation capacity:

- **Bulk hydrogen and oxygen facility**. Bulk facility installations of hydrogen and oxygen use large truck trailers or cryogenic tanks. The bulk gases are then filtered, purified and then piped to each individual furnace. Many municipalities highly regulate these installations and generally prohibit permitting in areas where other businesses or residences might be effected by a leak or explosion. In addition to permitting issues, infrastructure investment is high for the tank farm installation as well as the piping of all welded high purity stainless steel lines. In some areas double containment may be required. Installation costs can run over $200 per foot with installations run hundreds to over thousand feet not uncommon in larger installations. Piping cost alone can easily exceed the cost of a Steamer.

- **Point of use gas cabinets**. Point of Use (POU) installation place a gas cabinet near the tool or in a chase area. For oxide thicker 100 nm, hydrogen and oxygen usage can require frequent cylinder change out. The cost of the gases, often are less than the labor required to change out and purge the lines. When dealing with pyrophoric gases two operators may be needed to meet safety regulations. The same piping costs generally still apply as well as hydrogen safety interlocks to prevent excessive hydrogen from reaching the tool without the matching oxygen flows. Because cylinders need to be changed out frequently, storage within the building may be limited, requiring additional space external to the building for storage of flammable gases. Permitting can again become a problem and limit or slow the expansion of the facility to add more wet thermal oxidation capacity.

- **RASIRC Steamer**. By replacing pyrolytic steam with steam generated from DI water, the DI water plant infrastructure can be used without incurring significant additional costs. The DI water for each steamer is less than 1.5 liters per hour which should not affect the DI water plant. Lines can be run ¼" or 6mm PFA tubing. Installations can typically be done by in house facility engineers or local mechanical contractors without extensive permits and safety issues and at minimum cost.

Cost of Ownership (ROI) will vary from location to location based on process and facility arrangement. Table 2 below compares costs against a bulk gas system and point of use gas, in terms of cost per wafer.

TABLE 2 – COST OF OWNERSHIP COMPARISON

	Point of Use Gas System	Bulk Gas system estimate	New RASIRC Steamer	WFO ROI (Months)
TOx Cost Factor	16.5	5.8	1.0	~ 3 mo

TABLE 2 NOTES:

1. Based on 1 fully loaded TOx furnace tube; one operating cycle.
2. Operating Cycle includes TOx run period plus tube maintenance and qualification periods averaged over 12 months.
3. TOx Cost Factor - includes only items that vary based on TOx arrangement.
    a. Materials (gas, water; excludes silicon)
    b. Depreciation (gas system infrastructure, Steamer cost/installation)
    c. Labor/support (Engineering, technicians)
    d. Maintenance
4. Cost Factors will vary based on each operation's unique arrangement, but serve as strong indicator of opportunity.
5. Cost Analysis – For more information on creating a cost comparison analysis for your facility, contact RASIRC.

MAINTENANCE

Maintenance and labor associated with operating the RASIRC Steamer is negligible once a stable process is established. The primary activity is to track heating element (lamp) hours for predicted replacement times.

ADVANTAGES FOR OTHER SIMILAR APPLICATIONS

Based on the results achieved by this particular WFO, advantages of the RASIRC Steamer become apparent:

- Film quality with a stable process – meets critical TOx performance requirements.

- Unit TOx Wafer Cost – significantly reduced and will vary only slightly over time.
- Rapid adoption – enables small manufacturing or R&D operations to start up or expand operations quickly because no gas system infrastructure is required (cost avoidance, reduced schedule, and safety).
- Reliable – providing maximum uptime and peace of mind.

REFERENCES

(1) Spiegelman, Jeff. **"**Alternative Method and Device to Purify and Deliver Water Vapor**"**.

(2) Spiegelman, Jeff. **"**Urea and Ammonia Removal from De-Ionized Water via Steam Purification**"**.

(3) Spiegelman, Jeff. **"**Improved Oxide Growth Rate and Uniformity through New Steam Delivery Method**"**.

ABOUT RASIRC

RASIRC develops products that purify and deliver ultra pure liquids and gases, with a primary focus on water vapor. RASIRC dryers, humidifiers and steam generators are of critical importance for many applications in the semiconductor, pharmaceutical, medical, biological, fuel cell, and power industries.

ABOUT THE AUTHORS

Jeffrey Spiegelman is the President of RASIRC and has a BS in bioengineering and MS in Applied Mechanics from University of California at San Diego. He has over 50 international patents and publications. Previously, he was founder and president of Aeronex until it was purchased by Entegris in 2003. In 2005, he founded RASIRC to address process purity and delivery issues around next generation chemistries, with an initial focus on water vapor.

Mark Holman is the President of Sterling Technology Services, LLC, a consulting firm specializing in serving manufacturing operations for technology-based businesses. Mark has served the semiconductor and related industries since 1990, primarily focusing on the areas of risk management, operations management, and facility design/construction. Mark has a BS in Mechanical Engineering from the University of Pennsylvania.